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Review article

The United States Department of Energy's Regional Carbon Sequestration Partnerships program: A collaborative approach to carbon management

John T. Litynski [a,b,*], Scott M. Klara [a,b], Howard G. McIlvried [c], Rameshwar D. Srivastava [c]

[a]National Energy Technology Laboratory, United States Department of Energy, Pittsburgh, PA 15236, United States
[b]National Energy Technology Laboratory, Morgantown, WV 26507, United States
[c]Science Applications International Corporation, National Energy Technology Laboratory, Pittsburgh, PA 15236, United States

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Abstract

This paper reviews the Regional Carbon Sequestration Partnerships (RCSP) concept, which is a first attempt to bring the U.S. Deparment of Energy's (DOE) carbon sequestration program activities into the "real world" by using a geographically-disposed-system type approach for the U.S. Each regional partnership is unique and covers a unique section of the U.S. and is tasked with determining how the research and development activities of DOE's carbon sequestration program can best be implemented in their region of the country.

Although there is no universal agreement on the cause, it is generally understood that global warming is occurring, and many climate scientists believe that this is due, in part, to the buildup of carbon dioxide (CO_2) in the atmosphere. This is evident from the finding presented in the National Academy of Science Report to the President on Climate Change which stated "Greenhouse gases are accumulating in Earth's atmosphere as a result of human activities, causing surface air temperatures and subsurface ocean temperatures to rise. Temperatures are, in fact, rising. The changes observed over the last several decades are likely mostly due to human activities, . . .". In the United States, emissions of CO_2 originate mainly from the combustion of fossil fuels for energy production, transportation, and other industrial processes. Roughly one third of U.S. anthropogenic CO_2 emissions come from power plants. Reduction of CO_2 emissions through sequestration of carbon either in geologic formations or in terrestrial ecosystems can be part of the solution to the problem of global warming. However, a number of steps must be accomplished before sequestration can become a reality. Cost effective capture and separation technology must be developed, tested, and demonstrated; a database of potential sequestration sites must be established; and techniques must be developed to measure, monitor, and verify the sequestered CO_2.

Geographical differences in fossil fuel use, the industries present, and potential sequestration sinks across the United States dictate the use of a regional approach to address the sequestration of CO_2. To accommodate these differences, the DOE has created a nationwide network of seven Regional Carbon Sequestration Partnerships (RCSP) to help determine and implement the carbon sequestration technologies, infrastructure, and regulations most appropriate to promote CO_2 sequestration in different regions of the nation. These partnerships currently represent 40 states, three Indian Nations, four Canadian Provinces, and over 200 organizations, including academic institutions, research institutions, coal companies, utilities, equipment manufacturers, forestry and agricultural representatives, state and local governments, non-governmental organizations, and national laboratories. These partnerships are dedicated to developing the necessary infrastructure and validating the carbon sequestration technologies that have emerged from DOE's core R&D and other programs to mitigate emissions of CO_2, a potent greenhouse gas. The partnerships provide a critical link to DOE's plans for FutureGen, a highly efficient and technologically sophisticated coal-fired power plant that will produce both hydrogen and electricity with near-zero emissions. Though limited to the situation in the U.S., the paper describes for the international scientific community the approach being taken by the U.S. to prepare for carbon sequestration, should that become necessary.

Keywords: Carbon dioxide sequestration; Geologic sequestration; Terrestrial sequestration; Regional partnership; Carbon dioxide database

* Corresponding author. NETL, 3610 Collins Ferry Road, Morgantown, WV 26507, United States. Tel.: +1 304 285 1339; fax: +1 304 285 4638.
E-mail address: john.litynski@netl.doe.gov (J.T. Litynski).

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1. Introduction

Although there is no universal agreement on the cause, it is generally accepted that global warming is occurring, and many climate scientists believe that this is due, in part, to the buildup of carbon dioxide (CO_2) in the atmosphere. According to the Third IPCC Assessment Report (IPCC, 2001), during the 21st century, CO_2 emissions will have to be reduced by a substantial amount to achieve stabilization of atmospheric greenhouse gas (GHG) concentrations in the atmosphere. These finding were reiterated in the summary presented in the National Academy of Science Report to the President on Climate Change, which stated "Greenhouse gases are accumulating in Earth's atmosphere as a result of human activities, causing surface air temperatures and subsurface ocean temperatures to rise. Temperatures are, in fact, rising. The changes observed over the last several decades are likely mostly due to human activities..." (NAP, 2001).

In the United States, emissions of CO_2 originate mainly from the combustion of fossil fuels for energy production, transportation, and other industrial processes. Roughly one third of U.S. anthropogenic CO_2 emissions come from power plants (EIA, 2003). The U.S. has committed to work toward the long-term reduction of CO_2 emissions resulting from the use of fossil fuels. Although improvements in the efficiency of energy production and use can make a significant contribution, this approach is unlikely to be sufficient by itself in achieving the desired long-term reductions. Another way to offset CO_2 emissions is through capture and sequestration of carbon, either in geologic formations or in terrestrial ecosystems, while continuing to use fossil fuels.

The effectiveness of decreasing CO_2 emissions through capture and storage is a function of the amount of CO_2 captured. However, due to the additional energy required for capture, transport, and storage, there is a reduction in the overall efficiency of power plants or industrial processes practicing CO_2 capture. Current technology can capture about 90% of the CO_2 in the feed to a capture plant, but as much as 30% more energy is needed to operate the system, resulting in a net emissions reduction of approximately 85% (IPCC, 2001).

There are two general approaches to CO_2 capture: either carbon can be removed before the fuel is burned or CO_2 can be removed from the flue gas. In this latter case, CO_2 capture can be facilitated by burning the fuel with pure oxygen, rather than air, known as oxyfuel combustion. Oxyfuel combustion has a high potential for reducing CO_2 separation and capture costs. However, research is needed to improve efficiency and reduce costs, particularly of CO_2 capture. There is considerable scope for new ideas to accelerate the development and introduction of capture technology. Klara and Srivastava (2002) recently reviewed the DOE research and development program in the area of CO_2 separation and capture, specifically addressing the status of research efforts related to promising pathways and potential technological breakthroughs.

In the process of geologic sequestration, CO_2 is captured, dehydrated, compressed (usually to a dense, supercritical state), transported, and injected into subsurface geologic formations, sometimes with potential economic benefits through incremental oil or coalbed methane production and sometimes simply for deep storage in saline formations. Fluids have been injected on a massive scale into the deep subsurface for many years—in some cases to dispose of unwanted chemicals, pollutants or by-products of petroleum production, in other cases to enhance the production of oil and gas, and in yet other cases to recharge depleted formations (Wilson et al., 2003). The principles involved in such activities are well established, and in most countries there are regulations governing these activities. Natural gas has also been injected and stored in the subsurface on a large scale in many parts of the world for many years. By comparison, to date only relatively small volumes of CO_2 have been injected.

Although geologic storage of CO_2 as a GHG mitigation option was first proposed in the 1970s (Marchetti, 1976), little was done until the 1990s (Law and Bachu, 1996; Kaarstad, 1992). In a little over a decade, geologic storage of CO_2 has changed from a concept of limited interest to one that is widely regarded as a potentially important option, although R&D in CO_2 storage is still, in many respects, in an embryonic stage. As such, the current state of knowledge is changing rapidly. By the late 1990s, in addition to a number of publicly and privately funded programs underway in Canada, Japan, Europe, and Australia (IPCC, 2001), a number of projects were initiated by the U.S. Department of Energy to address the issues involved in storing CO_2 in geologic formations (Klara et al., 2003). In the U.S., depending on location, geologic reservoirs include coal seams, depleted oil and gas fields, and onshore deep saline formations. However, if the potential of geologic sequestration is to be realized, environmental impacts and the degree of certainty of CO_2 storage must be addressed. Legal issues also need to be addressed before geological sequestration is implemented on a national level (Rankin, 2004).

Another approach is terrestrial sequestration, in which carbon is stored in plants and soils through the photosynthetic activity of green plants and through the actions of bacteria and other microorganisms. The DOE's research program in natural sequestration highlights fundamental and applied studies, such as the development of measurement, monitoring, and verification technologies and protocols and field tests aimed at developing techniques for maximizing the productivity of degraded soils and ecosystems and, in particular, reclaiming surface mined lands (Litynski et al., in press).

Although sequestration looks very promising as a method for CO_2 mitigation, a number of steps must be accomplished before this option can become a reality. A database of potential sequestration storage sites must be established; technology developed, tested, and demonstrated; and techniques developed to measure, mitigate, and verify (MMV) the sequestered CO_2. In addition to determining storage capacity, it is important to determine how securely and safely the CO_2 is sequestered. Of the many risks, the ability to prevent CO_2 leakage is the central issue for all methods of storage. Effective MMV is critical to the success of CO_2 storage projects and will provide the basis for operators, regulators, and stakeholders to ensure the safe, permanent storage of CO_2. MMV techniques and protocols will be critical tools used to validate carbon credits if trading markets are implemented in a carbon constrained economy.

1.1. Regional issues in the United States

Geographical differences in fossil fuel use and potential sequestration storage sites across the United States dictate the use of regional approaches to address the sequestration of CO_2. To accommodate these differences, the DOE has created a nationwide network of seven Regional Carbon Sequestration Partnerships (RCSP) to help determine and implement the technology, infrastructure, and regulations most appropriate to promote CO_2 sequestration in different regions of the nation. These partnerships currently represent 40 states (Fig. 1), three Indian Nations, four Canadian

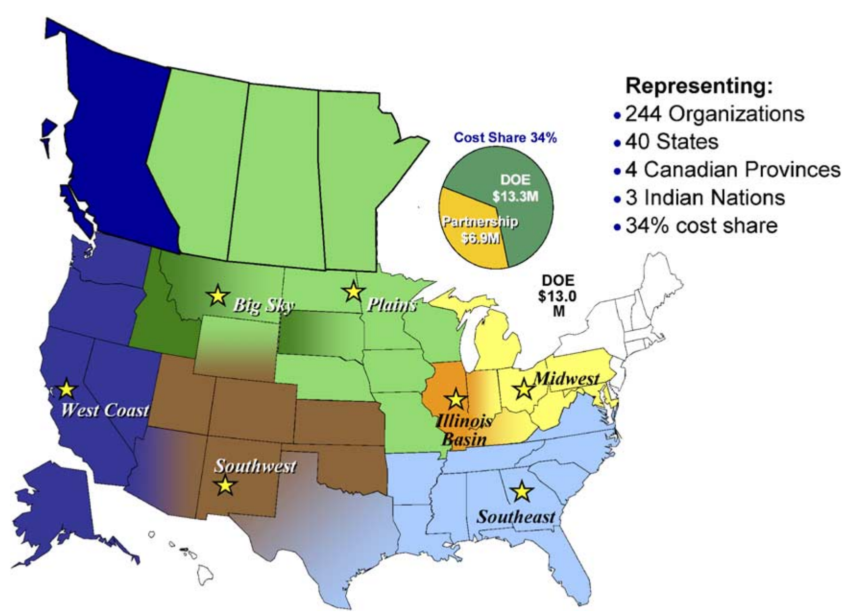


Fig. 1. Map showing locations of regional partnerships.

Provinces, and more than 200 organizations, including academic institutions; research institutions; industry; state and local governments; nongovernmental organizations; and several national laboratories. The novelty of this strategy is that it provides a means to develop a multi-region, multi-technology framework for decision making that addresses various regional differences while providing regional and national strategies for the effective reduction of CO_2 emissions.

The RCSP Program strategy provides a key linkage to several complementary programs within the Office of Fossil Energy. The RCSP supports FutureGen, a highly efficient and technologically sophisticated coal-fired power plant that will produce both hydrogen and electricity with near-zero emissions (OFE, 2004), by providing an assessment of potential geologic sinks, sequestration technologies, and regulatory permitting requirements, both regionally and nationally, that will be required for wide scale deployment of FutureGen technology. In addition, the RCSP has a fundamental linkage to the core R&D activities of the Sequestration Program, which provide the "R&D pipeline" that feeds technology related to capture, transport, injection, and monitoring of CO_2 to the RCSP. FutureGen and Core R&D are programs aimed at utilizing coal to produce electric power, hydrogen, and similar products with economic, near zero emissions technology. Finally, the work being performed by the partnerships will support future policy decisions related to carbon management, regulatory requirements, and the implementation of sequestration projects nationally.

The purpose of this review is to highlight the objectives and status of the RCSP Program. It examines CO_2 sources and potential sequestration sites, technology deployment issues, including the transportation infrastructure, and regulatory issues in different regions of the country and describes, for the benefit of the international scientific community and other interested parties, DOE's approach to preparing for carbon sequestration on a national basis, should that become necessary. Because this is a government sponsored program, it is important for the public to understand the rationale behind the program.

2. Creation of the regional partnerships

In September 2003, the DOE created a nationwide network of seven regional partnerships (Fig. 1) to promote CO_2 capture and sequestration in the different geographic regions of the nation represented by the partnerships. These partnerships currently include 40 states that represent an area encompassing 97% of coal-fired CO_2 emissions, 96.5% of industrial CO_2 emissions, 96% of the total land mass, and essentially all the geologic sinks in the United States that are potentially available for carbon sequestration (Fedstats, 2005; EIA, 2002–2003, 2004, 2005). These seven partnerships are studying which of the numerous sequestration approaches that have emerged in the last few years are best suited for their specific regions of the country and are developing the framework needed to validate and potentially deploy the most promising carbon sequestration technologies. They are also beginning to study the infrastructure requirements, regulatory framework, and public education and involvement necessary within their regions should policy decisions, supported by climate science, dictate that sequestration be widely deployed in the future. This effort is aimed at enabling the continued use of domestic energy resources, particularly coal, and the existing energy infrastructure, as well as the development of new resources related infrastructure, in a socially and environmentally acceptable manner.

As indicated in Fig. 1, the seven regional partnerships selected by DOE are:

- Big Sky Carbon Sequestration Partnership (BSCSP)
- Midwest Geological Sequestration Consortium (MGSC)
- Midwest Regional Carbon Sequestration Partnership (MRCSP)
- Plains CO_2 Reduction Partnership (PCOR)
- Southeast Regional Carbon Sequestration Partnership (SECARB)
- Southwest Regional Partnership for Carbon Sequestration (SRPCS)
- West Coast Regional Carbon Sequestration Partnership (WESTCARB).

2.1. Objectives

In addition to evaluating CO_2 sequestration technologies that are most appropriate for their regions, both existing and being developed under the DOE Core R&D program and other programs, each partnership has been asked to focus on the following five major objectives.

2.1.1. Characterization of CO_2 sources

The first objective is to catalog the major point sources of anthropogenic CO_2 emissions in their region. In general, three major categories of GHG sources were surveyed: fossil fuel power plants; industrial plants, including metals manufacturing, chemical processing, and ethanol production; and agricultural sources. Various public databases from Federal, State, and Local agencies are being combined with data from industry to create regional and national lists of CO_2 point sources. The effluent gases from these sources will be used to match potential capture technology option with each source.

2.1.2. Characterization of geologic sequestration sites

The second objective is to assess potential geologic CO_2 sequestration sites within their region, including saline formations, unminable coal seams, and oil and gas formations. The feasibility of various sinks to sequester CO_2 is dependent on the physical characteristics of the sinks, the availability of the necessary infrastructure required for large-scale sequestration, and socio-economic and political considerations (Bachu, 2000). The most important physical characteristics include large capacity, high injectivity, and a suitable geologic environment for safe long-term storage. Geologic sequestration relies on a containment layer, capable of trapping high pressure CO_2, located over the geologic formation into which the CO_2 is being injected. Attractive geologic formations should have high permeability and porosity combined with a wide areal extent and should not be seismically active or have significant faulting or fracturing that could breach cap rock integrity. Storage in oil/gas formations or coal beds can result in the production of additional hydrocarbons that can be used to partially offset costs.

The potential for geologic sequestration will be evaluated using hydrochemical analysis techniques and existing groundwater data to evaluate the suitability of each formation as a long-term carbon sequestration site. This analysis will assess the interconnectedness of subsurface flow systems and estimate the amount of CO_2 that can be expected to be hydrodynamically trapped. Dissolved CO_2 forms a weak acid that can be neutralized by weathering or corroding subsurface minerals to produce carbonate and bicarbonate ions and/or mineral carbonates. Of particular importance are weathering reactions of silicate minerals rich in Ca, Mg, and Fe. Thermodynamic considerations indicate that, for any CO_2 pressure important for sequestration, some minerals will convert to calcite and a clay mineral, entombing the introduced CO_2 as solid calcium carbonate. The timeframe and extent of mineralization trapping for a given subsurface environment is a function of the silicate weathering rate and the abundance of appropriate silicate phases. Tabulated bulk chemistry and mineralogy of the host rocks will be used to assess the mineralization potential of regional sinks (Xu et al., 2004).

2.1.3. Characterization of terrestrial sequestration opportunities

The third objective (for six of the seven partnership regions) is to assess the potential for terrestrial carbon sequestration. Terrestrial carbon sequestration relies on land management practices and technologies to remove CO_2 from the atmosphere and store it in trees, other plants, and soils. Soils contain the largest pool of carbon in the terrestrial biosphere; agricultural/grazing land soils in the U.S. typically contain 1–5 wt.% organic carbon, a 30–50% reduction over levels which existed a century ago. Thus, these soils represent a large potential sink for CO_2. Forests in the United States are net absorbers of carbon and offset approximately 11.9% of the 2002 U.S. emissions. The rate of carbon sequestration in this sink is slowing, because many abandoned and unproductive lands in the 19th and early 20th centuries have now evolved into mature forests (EIA, 2003). Several studies indicate that an increased effort to adopt land use changes and management practices that enhance soil organic matter or converting agricultural land into forests can result in the sequestration of significant amounts of carbon (Lal, 2004; Lal et al., 1998; Antle and Capalbo, 2001). Several options that can increase the amount of carbon in the soil are available to landowners, such as improving tillage practices and switching to no-till or reforesting abandoned or unproductive farm lands.

The availability and value of credits for storing carbon in soil and vegetation could alter economic returns and affect future land use. Winrock (EPRI and CEC, 2004) has developed methods for determining the expected costs for various project activities. These costs are a function of land value and use, conversion costs, opportunity costs, annual maintenance costs, transaction costs, including MMV, lost earning from existing land use, and potential income from new land use.

2.1.4. Characterization of transportation infrastructure

The fourth objective is to determine transportation capabilities and needs in their region. Transportation information, such as pipeline and rail infrastructure, will be derived from siting boards and transportation departments. Options for transporting compressed liquefied CO_2 from an industrial capture site to a geologic storage site include rail, highway, ship or barge, and pipeline. It is likely that, with few exceptions, large-scale sequestration projects will use dedicated pipelines due to the large CO_2 volumes involved and the gas's characteristics. The partnerships are investigating what the specification for compressed CO_2 should be. Varying specifications, such as those from Kinder Morgan and Dakota Gasification, reflect the differences allowed between sites. The partnerships are working on establishing a list of potential gas impurities and their acceptable ranges (Dakota Gasification Company, 2003).

2.1.5. Geographic information system and database development

The fifth objective is to assemble the accumulated data in appropriate databases and geographic information systems (GIS). A major deliverable for each partnership will be a GIS for their region providing information on CO_2 sources, potential sequestration sites, relevant infrastructure, and related factors in their region. Each GIS is being used in a decision support system to screen potential storage formations, identify transportation fairways, match sources and sinks, and assess risks, such as the location of faults and the distance to population centers. The partnerships are working together to ensure consistency between systems by developing standards for data formats and metadata requirements.

The DOE is currently funding the development of a distributed national database for carbon sequestration (NATCARB) (NETL, 2004; Kansas Geological Survey, 2004). This is a distributed database relying upon sources of information located on servers throughout the United States to create a virtual database and GIS capable of viewing and analyzing data related to the capture, transport, and sequestration of CO_2 in geologic formations nationwide. Developers of NATCARB are working with information technology contacts at each of the seven partnerships to link their databases into the NATCARB structure. The result is a national system where data from all seven partnerships can be viewed and analyses conducted from a single web portal.

2.2. Regulatory requirements

Before geologic sequestration of CO_2 can occur, a suitable permitting framework will have to be developed and implemented for CO_2 capture, transportation, and injection. Permitting of sequestration projects will require that potential environmental risks be understood and that mitigation strategies be in place. Applicable permitting requirements will be compiled into a database, and the associated regulatory language will be classified as applicable to technology validation field testing, large-scale demonstration and deployment, or both. Provisions that would encourage the adoption, as well as factors that may be barriers to deployment, of sequestration technologies will be identified. A series of interviews and stakeholder meetings with regulators, key government agencies, state legislators, owners of generating plants, and environmental groups will be held. In collaboration with the seven regional partnerships, the Interstate Oil and Gas Compact Commission (IOGCC) recently published a framework for geologic sequestration. The framework was developed after a review of each state's permitting requirements that would affect CO_2 capture, transport, and injection (IOGCC, 2005).

2.3. Monitoring, mitigation, and verification requirements

The primary activities at a CO_2 storage site will be compression, metering, distribution through surface piping to individual injection wells, injection, and monitoring. The experience at the approximately 80 enhanced oil recovery (EOR) projects and other underground injection control (UIC) program wells in the U.S. will be evaluated to understand environmental risks, monitoring requirements, safety concerns, response to inadvertent leaks, and similar issues.

Modeling potential failures and their impacts is critical to developing mitigation techniques that minimize the possibility of slow or catastrophic releases of CO_2. Environmental risks differ between geologic sequestration and terrestrial sequestration. Terrestrial sequestration generally relies on applying known techniques to enhance soil quality and biomass productivity. In most circumstances the environmental risks associated with terrestrial sequestration are likely to be negligible, and there may even be environmental benefits. Acceptable land management practices will need to be documented so that the public will accept terrestrial sequestration as a valid long-term CO_2 mitigation technique.

2.4. Communications with stakeholders and action plan development

Each partnership is working to communicate with interested stakeholders in the region and assess public opinion through a series of workshops, conferences, and dissemination of public outreach materials. These efforts will culminate in an action plan to engage and educate the public about carbon sequestration technologies in preparation for possible future deployment activities.

2.5. Action plans for field validation of most promising sequestration technologies

At the conclusion of Phase I, 2 years from the start of the program, each partnership will recommend projects for small-scale validation testing of the most promising opportunities in their region. These action plans for project implementation will include technical requirements, regulatory permitting, methods to gain stakeholder support, and development of an atlas detailing the available sources, sinks, and infrastructure available for carbon sequestration technology deployment.

3. Partnership descriptions

Since each region of the country is unique, each partnership consists of regional members with different priorities as they complete the Phase I goals. Each partnership is responsible for identifying all the significant stationary sources within its region (Table 1); the potential sites for sequestering CO_2, including possibilities for both direct injection into geologic formations and indirect uptake into terrestrial sequestration sinks; and other infrastructure needs, including capture and purification requirements and design of injection wells. Table 2 presents the responsibilities of the lead organizations in each partnership, while Figs. 2–8 list all the organizations involved.

3.1. Big Sky Carbon Sequestration Partnership

The Big Sky Carbon Sequestration Partnership (BSCSP), led by Montana State University, encompasses Idaho, Montana, and South Dakota (Fig. 2). The partnership is composed of universities, state agencies, national laboratories, Native American tribes, industry, and consulting organizations. BSCSP believes that to successfully implement CO_2 sequestration projects, it must engage people from various backgrounds on why carbon sequestration is so critical, inform them of the potential benefits and environmental and public safety issues, and address their questions and concerns.

BSCSP proposes three pathways to address project implementation issues: (1) establish the Carbon Sequestration Innovation Network to define specific implementation

Table 1
Estimated CO_2 emissions from large point sources in the regional partnerships

Plant type	CO_2 emissions from large point sources, kt/year							
	BSCSP	MGSC	MRCSP	PCOR	SECARB	SRPCS	WESTCARB	Total
Utility								
Coal	5543	256,256	625,900	358,898	671,195	455,253	83,400	2,456,445
Natural Gas	12,189	5006	9900	7064	150,541	133,764	52,200	370,664
Oil	24	48	4137	43	35,067	99	300	39,718
Non-utility								
Refinery	7238	9703	19,863	14,523	39,452	0	25,000	115,779
Gas processing	2880	0	13,607	8709	15,862	0	0	41,058
Ethanol	435	3848	446	17,908	0	0	0	22,637
Ammonia	0	214	21	2042	9443	2825	0	14,545
Iron and steel	0	3857	70,327	4531	2560	0	0	81,275
Other	677	4338	17,704	130,906	71,326	6600	14,000	245,551
Total	28,986	283,270	761,905	544,624	995,446	598,541	174,900	3,387,672
Increase from 1990 to 2000	15.7%	21.4%	11.2%	22.7%	22.4%	19.4%	14.1%	18.4%

strategies, (2) improve the framework for voluntary carbon markets, and (3) develop a risk assessment and decision support framework to assess the most viable projects and optimize carbon storage options.

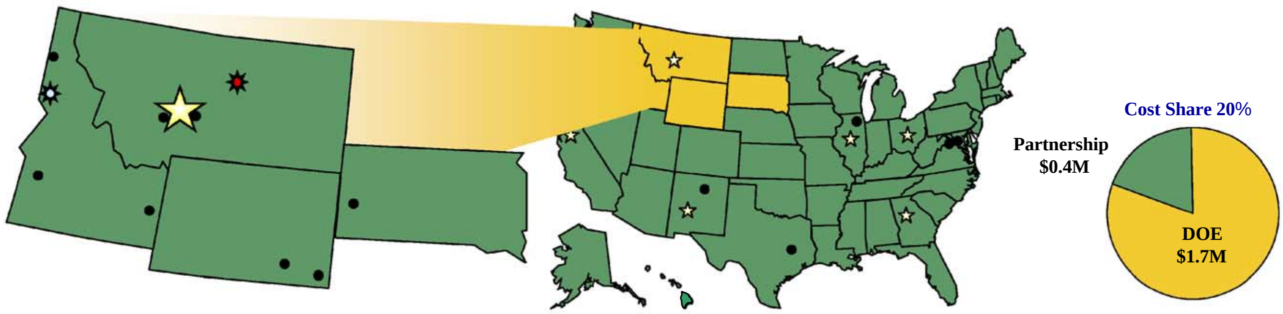
Within the region are three major geological terrains with high geologic sequestration potential: the Snake River Plain, the Williston Basin, and the Powder River and associated basins. The Snake River Plain is a prominent structural depression stretching across Southern Idaho composed of two distinct volcanic provinces. Both provinces host large formation systems that have been well characterized. The Eastern Snake River Plain may be ideally suited for CO_2 sequestration because its layer cake morphology, comprised of numerous thin basalt flows and intercalated sedimentary interbeds, reduces vertical permeability. Additionally, the mineralogy found within the plain is such that the Snake River Plain has high potential for mineralization trapping. A mineralization rate model has been developed to determine the fate of CO_2 injected into mafic volcanic rock formations which shows that, after 150 years, mineralization dominates storage (Smith, 2004). This, together with the large volume of sediments, indicates a potential for sequestration of billions of tons of CO_2.

The Williston Basin is a large sedimentary structure stretching across several states and Canadian provinces. The U.S. portion of the basin is estimated to hold natural gas reserves of more than 13 trillion cubic feet. The basin's depth and structure make it a productive hydrocarbon formation. These same geologic features will likely make it suitable for CO_2 sequestration. The Powder River Basin, which covers a large area of South Central Montana and Northern Wyoming, is composed of alternating layers of sandstone, shale, and in some places thick deposits of coal. Like the Williston Basin, the Powder River Basin hosts large deposits of hydrocarbons and coal and has significant potential for CO_2 sequestration. Coal bed methane production in the Powder River Basin is expected to increase significantly over the next 10 years.

Table 2
Focus area leads for each partnership

Focus area	Partnership						
	BSCSP	MGSC	MRCSP	PCOR	SECARB	SRPCS	WESTCARB
Lead organization	MSU	ISGS	Battelle	EERC	SSEB	NMIMT	CEC
Geologic sinks and MMV	U of Idaho/INL/LANL	ISGS	Battelle/OGS	EERC	EPRI/ARI	UGS/LANL/TX BEG	LBNL
Terrestrial sinks and MMV	MSU	N/A	OSU	NDSU/USGS/DU	Winrock Int	USDA NRCS	Winrock Int
Sources/capture/transportation	INL	ISGS	Battelle	EERC	DIAL	NMIMT	EPRI
GIS/databases	LANL/INL	ISGS	Battelle	EERC	MIT	UGS	EPRI
Public outreach	Entech Strategies	ISGS	Battelle/AJW	EERC	SSEB	NMIMT	LBNL
Regulatory compliance	INL	IOGCC	NRRI	EERC	SSEB	WGA	CEC
Economics/risk analysis	MSU	ISGS	Battelle	EERC	MIT	NMIMT	CEC

AJW—AJW, Inc., ARI—Advanced Resources International, CEC—California Energy Commission, DIAL—Diagnostic Instrumentation & Analysis Laboratory, DU—Ducks Unlimited, EERC—Energy and Environmental Research Center, EPRI—Electric Power Research Institute, INL—Idaho National Laboratory, IOGCC—Interstate Oil and Gas Compact Commission, ISGS—Illinois State Geological Survey, LANL—Los Alamos National Laboratory, LBNL—Lawrence Berkley National Laboratory, MIT—Massachusetts Institute of Technology, MSU—Montana State University, NDSU—North Dakota State University, NMIMT—New Mexico Institute of Mining and Technology, NRRI—National Regulatory Research Institute, OGS—Ohio Geological Survey, SSEB—Southern States Energy Board, TX BEG—Texas Bureau of Economic Geology, UGS—Utah Geological Survey, USDA NRCS—U.S. Department of Agriculture National Resource Conservation Service, USGS—U.S. Geological Survey, WGA—Western Governors Association.



Description :
The Northern Rockies and Great Plains Regional Carbon Sequestration Partnership, led by Montana State University, Bozeman, MT, will: identify and catalogue CO2 sources and promising geologic and terrestrial storage sites, develop a risk assessment and decision support framework to optimize the areas' carbon-storage portfolio, enhance market-based carbon-storage methods, identify and measure advanced greenhouse gas-measurement technologies to improve verification, support voluntary trading and stimulate economic development, call upon community leaders to define carbon-sequestration strategies, and create forums that involve the public.

Partners:
- Boise State University
- ☆ EnTech Strategies, LLC / New Directions
- Environmental Financial Products
- Environmental Financial Products
- ☆ Idaho National Engineering and Environmental Lab.
- Inland Northwest Research Alliance
- Jackson Hole Center for Global Affairs
- ☆ Los Alamos National Laboratory
- Montana Bureau of Mines and Technology
- Montana Dept. of Environmental Quality
- Montana GIS Services Bureau IT Services
- Montana Governor's Carbon Sequestration Working Group
- Nez Perce Tribe
- ☆ Montana State University
- National Carbon Offset Coalition
- Nez Perce Tribe
- Pacific Northwest National Lab (PNNL)
- Puget Sound Energy (PSE)
- South Dakota School of Mines and Technology
- Texas A & M University
- The Confederated Salish and Kootenai Tribes
- The Sampson Group
- U of Wyoming Geographic Information Science Center
- U of Wyoming Institute for Energy Research
- U of Wyoming Ruckelshaus Institute for Environment & Natural Resources
- Unifield Engineering, Inc.
- ☆ University of Idaho
- Western Governors' Association
- Wyoming Carbon Sequestration Advisory Committee / U of Wyoming
- Wyoming Department of Environmental Quality

Fig. 2. Big Sky Carbon Sequestration Partnership.

The region contains large areas of forest that have great potential to sequester carbon. Rangelands comprise a sizeable portion of the land resources in the region. It is estimated (Schuman et al., 2002) that rangelands can store 0.1–0.3 Mg/ha/year additional carbon, with new grasslands storing as much as 0.6 Mg/ha/year. Reductions in soil erosion and offsite transport of carbon, as well as calcium carbonate accumulation in grazing land soils, through improved land management offer additional opportunities to manage soil carbon storage. The South Dakota School of Mines and Technology (SDSM&T) has developed a program, called C-Lock, that provides estimates of the amount of soil carbon that is sequestered as a result of land use management decisions. SDSM&T will develop a spatially linked database of forest resources in the region that will serve as the basis for a carbon sink assessment framework.

In addition, there are a number of abandoned mine lands that have the potential to be reclaimed and reforested to maximize carbon storage. These sites will be identified, and their carbon sequestration potential will be assessed. Overall, this region appears to have significant possibilities for using its terrestrial sequestration potential for carbon trading purposes.

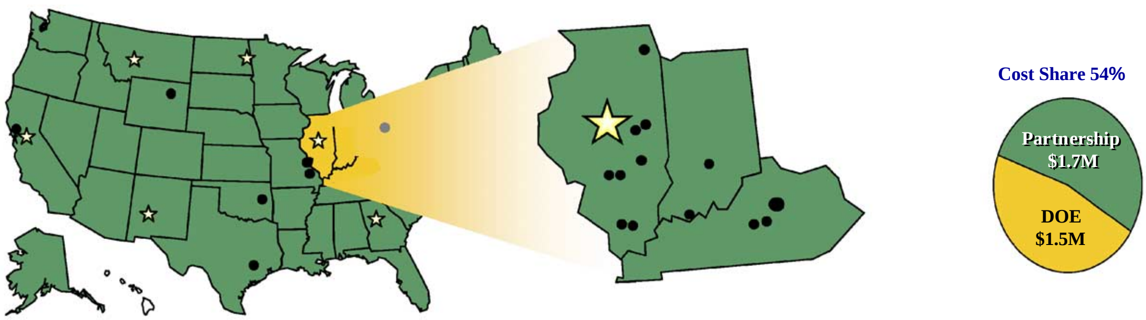
BSCSP will develop a risk assessment and decision support tool to optimize the region's carbon storage portfolio, enhance market-based, voluntary approaches to carbon storage, and support voluntary trading. The tool will incorporate a number of elements including system costs (capture, transport); external costs (environmental, societal); sequestration effectiveness (duration, quantity, uncertainty); and legal and regulatory barriers.

BSCSP will identify and apply advanced GHG measurement technologies to improve verification protocols, support voluntary trading, and stimulate economic development. They will engage community leaders to define carbon sequestration implementation strategies and create forums to inform and secure input from the public.

3.2. Midwest Geological Sequestration Consortium

The Midwest Geological Sequestration Consortium (MGSC) will assess the geological carbon sequestration options in the Illinois Basin, which encompasses most of Illinois, along with Western Indiana, and Western Kentucky (Fig. 3). MGSC, led by the Illinois State Geological Survey, involves more than 20 organizations, including academia, private companies, and state agencies.

The 155,000 km^2 Illinois Basin is home to one of the highest concentrations of stationary sources of CO_2 in the nation and includes utilities, cement plants, and ethanol production facilities that together emit in excess of 230 million tonnes of CO_2 annually. The Illinois Basin contains about 500,000 km^3 of sedimentary rocks with a maximum thickness of 10,000 m in the deepest part of the basin in Western Kentucky. The basin includes saline formations at 1100 m and deeper, mature oil formations in the range of 300–1200 m, and unminable coal seams at 250–430 m. Illinois possesses the largest resource of bituminous coal of any state, 211 billion tonnes, of which 56 billion tonnes are



Description :

The Midwest Geological Sequestration Consortium, headed by the University of Illinois - Illinois State Geological Survey, will look at ways of storing CO2 within deep, uneconomic coal seams, numerous mature oil fields and saline reservoirs that lie beneath the 60,000 square mile Illinois Basin, which underlies most of Illinois, western Indiana and western Kentucky. The consortium will assess technical and economical options to determine the feasibility of using these geological sinks for long-term storage. This involves: 1.) developing a database and assessing CO2 capture and transport in the region, 2.) focusing on storage for 13-15 months for each of the three sinks, and 3.) linking integrated options for capture, storage and transportation with environmental and regulatory framework to define sequestration scenarios and outcomes for the region.

Partners:

- Air Liquide
- Ameren
- Aventine Renewable Energy
- Brigham Young University
- Cinergy Corp.
- D.J. Nyman & Associates
- Electric Power Research Institute (EPRI)
- IL Dept of Commerce & Economic Opportunity
- Illinois Corn Growers Association
- Illinois Department of Natural Resources
- Illinois Oil and Gas Association
- ☆ **Illinois State Geological Survey**
- Indiana Geological Survey, Indiana University
- Indiana Oil & Gas Association
- ☆ Interstate Oil and Gas Compact Commission (IOGCC)
- Kentucky Geological Survey, University of Kentucky
- Kentucky Oil & Gas Association
- Louisville Gas and Electric Energy
- Peabody Energy
- Southern IL University
- University of Illinois

Fig. 3. Midwest Geological Sequestration Consortium.

considered to be recoverable. Illinois has over 600 oil and gas fields, many of which are nearing the end of conventional production, that offer potential for CO_2 sequestration. Illinois is the second leading state in natural gas storage capacity. Many of these facilities are in the Mt. Simon sandstone and prove that this deposit has gas containment capability, as well as providing a database of cores, water chemistry data, and formation properties. These geologic formations offer a volumetrically large sequestration potential in the region.

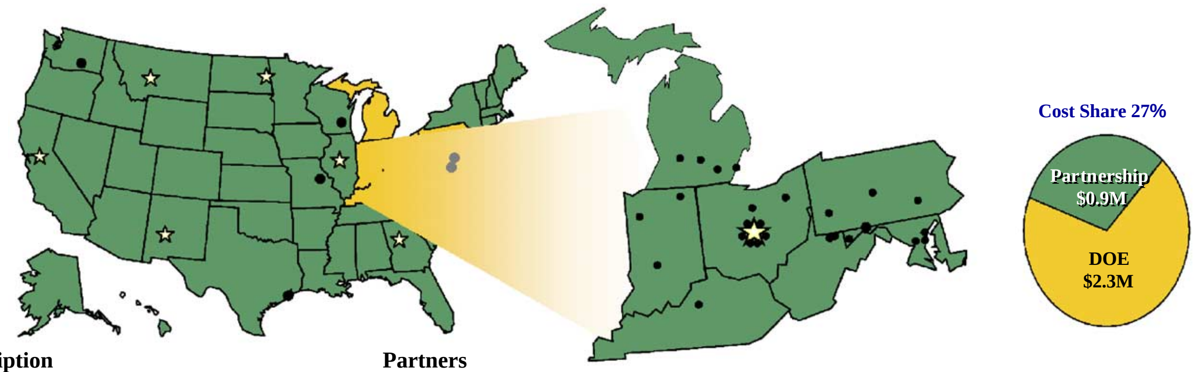
Illinois has about 8.8 million ha of farmland planted in corn and soybeans. Forests are much more limited, amounting to about 1.7 million ha in Illinois and 1.8 million ha in Indiana. Unreclaimed mine lands in Illinois offer little opportunity for terrestrial sequestration, since they amount to only 2200 ha. Thus, the focus of terrestrial sequestration in the Illinois Basin is on increasing soil carbon as a result of improved agricultural practices.

Transportation options will be assessed at two different scales. First, as potential sites for technology validation field tests are determined, CO_2 sources of sufficient magnitude will be identified that do not require expensive flue gas separation and capture. One option will be CO_2 from fermentation of corn to produce ethanol; this volume of CO_2 may be transported by tank car or truck. Second, larger volume transportation via pipeline will be assessed to determine the potential for movement of million tonne and greater quantities of CO_2 from sources to geologic sequestration sites. National Pipeline Mapping System (NPMS) data for Illinois, Indiana, and Western Kentucky will be compiled and joined using ArcGIS to show pipeline corridors that may offer suitably aligned rights-of-way for future large-scale CO_2 transport. A comprehensive assessment of CO_2 transportation options, both pipeline and truck/rail, has been completed to determine the costs of CO_2 transportation in a hypothetical 200-mile fairway.

For their public outreach efforts the MGSC will create a web site, hosted at the Illinois State Geologic Survey and linked to the web sites of other geologic surveys and the MIDCARB, to publicize results of the MGSC effort. MGSC's site will provide information on the Illinois Basin and background on sequestration science and links to other sequestration information sites. MGSC will also create a carbon sequestration science teaching module to assist teachers in grades 4 through 12.

3.3. Midwest Regional Carbon Sequestration Partnership

The Midwest Regional Carbon Sequestration Partnership (MRCSP), which covers the states of Indiana, Kentucky, Maryland, Michigan, Ohio, Pennsylvania, and West Virginia, is being led by Battelle Memorial Institute (Fig. 4). Battelle is a global leader in developing innovative carbon management solutions and is currently leading the DOE and industry sponsored Ohio River Valley CO_2 Storage Project to evaluate the potential for sequestration in geologic formations in the vicinity of American Electric Power's Mountaineer power plant and, if feasible, to conduct CO_2 sequestration tests in the deep saline formations in future phases of the project. MRCSP consists of 39 partners, including state geological surveys, educational institutions, research institutions, energy companies, and other organizations. Thus, MRCSP represents a



Description

The Midwest Regional Carbon Sequestration Partnership, led by Battelle Memorial Institute, Columbus, OH, will identify greenhouse gas sources in its region - which covers Indiana, Ohio, Kentucky, West Virginia, Pennsylvania, Michigan, and Maryland - and determine the technical feasibility and cost of capturing and sequestering these emissions in deep geologic formations and agricultural forests and degraded land systems. Existing regulations and policies will be examined to determine if they hinder the cost-effectiveness of CO2 sequestration options, and ways of overcoming these barriers will be outlined. The partnership is comprised of various universities, geological surveys, coal, and utility industries from the region.

Partners

- American Electric Power
- AES Warrior Run
- ☆ AJW Group
- Alliance Resource Partners
- Arch Coal Inc.
- Baard Energy
- Babcock & Wilcox
- ☆ **Battelle Memorial Institute**
- British Petroleum
- CEED
- Cinergy Corp.
- CONSOL Energy Inc.
- Constellation Energy
- DTE Energy
- First Energy
- Indiana Geological Survey
- Kentucky Geological Survey
- Maryland Energy Administration
- Maryland Geological Survey
- Monsanto
- ☆ NRRI
- Ohio Coal Development Office
- Ohio Corn Growers Association
- ☆ Ohio Division of Geological Survey
- Ohio Environmental Council
- Ohio Forestry Association
- Ohio Soybean Council
- ☆ Ohio State University
- Ohio Turfgrass Foundation
- Pacific Northwest National Laboratory
- Pennsylvania Geological Survey
- Pennsylvania State University
- Purdue University
- Scotts Company
- The Keystone Center
- University of Maryland
- WV Geological and Economic Survey
- West Virginia University
- Western Michigan University

Fig. 4. Midwest Regional Carbon Sequestration Partnership.

diverse collection of organizations, which are actively exploring the feasibility of deploying advanced carbon management technologies. The partnership is tackling the challenge of reducing CO_2 emissions in the Midwest Region while simultaneously protecting the economic base of this highly industrialized region.

MRCSP is organized into five subgroups for the study of Geologic Formations, Terrestrial Reservoirs, Sequestration System Technologies and Economics, Regulatory Analysis, and Stakeholder Outreach and Education. MRCSP will lay a foundation to help stakeholders understand the technical, regulatory, and environmental issues related to carbon sequestration and to help facilitate stakeholder acceptance of potential deployment of carbon sequestration technologies.

The region contains nearly 500 large point sources of anthropogenic CO_2, including power plants, refineries, cement plants, and iron and steel plants, which have a combined emissions rate of more than 700 million tonnes of CO_2 annually (see Table 1) (Dahowski and Dooley, 2003). In addition there are 21 million ha of farmland that emit methane and nitrogen oxides. In 1990, the region emitted more than 5.0 million tonnes carbon equivalent of high global warming potential GHGs.

The region possesses an abundance of potential geologic and terrestrial CO_2 reservoirs, including large areal extents of deep coal seams, deep saline formations, and basalt formations. There are also a large number of oil and gas formations at appropriate depth for sequestration combined with EOR.

The region also contains a variety of terrestrial sequestration options, such as prime cropland, eroded cropland, marginal cropland, forests, surface mining areas, and wetlands. For example, the region contains a large area of degraded and abandoned mine lands that, if properly restored, could serve as an important terrestrial sequestration reservoir. In addition, an estimated 21,000 ha of new mine lands are permitted each year, whose restoration back to forests or agricultural lands will be necessary. MRCSP will also study the sequestration potential, regional heterogeneity, and strategies to enhance carbon sequestration in these biomass and soil related sinks.

Given the high density of large point sources in some parts of the region, a network of pipelines will likely emerge as CO_2 capture and sequestration technology is deployed. Because the vast majority of large CO_2 point sources in the region are in close proximity to possible geologic sequestration sites, it is anticipated that CO_2 pipeline lengths will not be very long. MRCSP will assess different CO_2 capture technologies and how these systems can be most economically matched to the region's wide diversity of CO_2 point sources. MRCSP will study the permitting requirements necessary to site CO_2 pipelines and examine the extent to which existing rights-of-way can be exploited for CO_2 pipeline use.

Within this region, disposal of liquid wastes in deep geologic formations has been employed for decades. This is an accepted practice and has proven to be safe and effective when properly designed, monitored, and implemented. Injection wells have been permitted through the state and

EPA Underground Injection Control Program. Environmental risks associated with geologic sequestration of CO_2 will be assessed and documented for each formation type studied by the MRCSP.

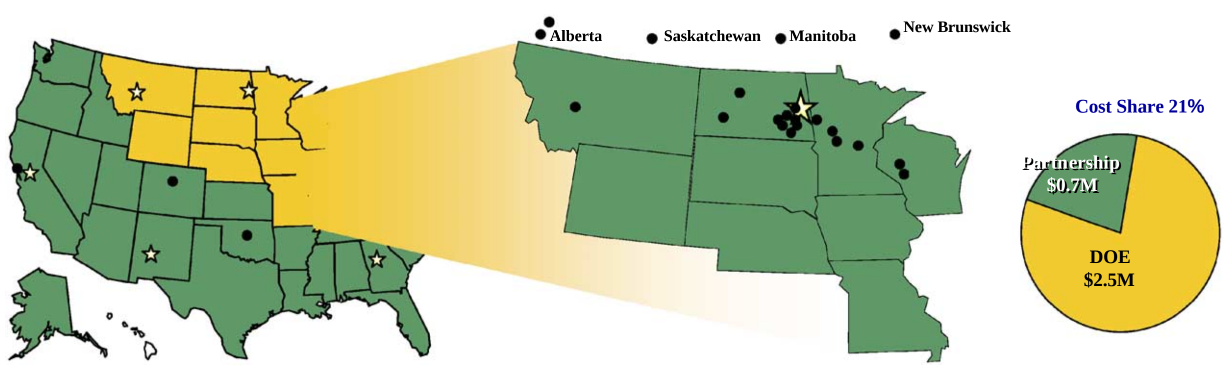
3.4. Plains CO_2 Reduction Partnership

The Plains CO_2 Reduction Partnership (PCOR), led by the Energy and Environmental Research Center (EERC), includes Iowa, Minnesota, Missouri, Montana, Nebraska, North Dakota, South Dakota, Wisconsin, portions of Wyoming, as well as Alberta, Manitoba, and Saskatchewan, Canada (Fig. 5). The PCOR Partnership region was defined on the basis of similarities in large stationary CO_2 sources, similarities in geologic and terrestrial CO_2 reservoirs, transport considerations of direct CO_2 sequestration, and the presence of two major value added, anthropogenic CO_2 EOR projects. The addition of the Canadian Provinces is critical to the strategy of the U.S. to mitigate CO_2 emissions, since these provinces offer significant opportunities for enhanced hydrocarbon recovery with CO_2 storage. The PCOR Partnership includes government, academic, industrial, and environmental organizations.

The PCOR Partnership will use a three-step approach to accomplish its goals. Step 1 is to characterize technical issues and the public's understanding and attitudes concerning CO_2 sequestration, including development of a database on sources, formations, separation and transportation options, regulatory permitting requirements, and environmental benefits and risks. Step 2 is to identify regional opportunities for sequestration and inform the pubic about options and risks. Step 3 is to develop a detailed action plan for implementing demonstration projects in the region.

PCOR has identified 1074 stationary CO_2 sources in the U.S. portion of the region; 55% of the sources are industrial, while 74% of CO_2 emissions are from electric utilities. The U.S. portion of the region emitted 164.3 million tonnes of carbon equivalent of anthropogenic CO_2 in 2000, about 10.5% of the U.S. total. Major stationary sources (commercial, industrial, and electric utilities) contributed two thirds of this total.

The region includes the Williston Basin and the Powder River Basin, both of which are significant hydrocarbon producing areas. These basins have active or planned sequestration projects related to value-added EOR or enhanced coal bed methane (ECBM) production, as well as recognized potential for sequestration in deep aquifers, exhausted hydrocarbon production units, and unminable coal seams. The semiarid rolling grasslands of the plains dominate the Western portion of the region and are currently used for grazing and growing small grains, and the forested landscape of the Northeast and North offers opportunities for testing and verification of soil and vegetative sequestration technologies. Agricultural soils in the region have the potential to take up 0.2–0.45 tonnes of carbon/ha. Canadian studies indicate that the 6 million ha of Minnesota forests have the capacity to take up about 0.27 million tonnes of carbon/year through 2050 (Gunter et al., 1998).



Description

The Plains CO2 Reduction Partnership, led by the Energy & Environmental Research Center at the University of North Dakota, Grand Forks, ND proposes a three-step approach that involves 1.) characterizing technical issues and the public's understanding regarding all aspects of CO2 sequestration, 2.) identifying regional opportunities for sequestration, and 3.) detailing an action plan to be carried out in Phase II of the Carbon Sequestration Regional Partnership solicitation. The region includes the Williston and Power River basins along with 29 coal-fired utilities, 27 ethanol-production facilities, and the Dakota Gasification facility that, together, account for about half of the region's CO2 emissions.

Partners

- Alberta Dept of Environment
- Alberta Energy and Utility Board
- Alberta Energy Research Inst
- Amerada Hess Corporation
- Basin Electric Power Coop
- Bechtel Corporation, Nexant
- CEED
- Chicago Climate Exchange
- Dakota Gasification Company
- ☆ Duck Unlimited Canada
- Eagle Operating, Inc.
- Encore Acquisition Company
- Environment Canada
- Excelsior Energy, Inc.
- Fisher Oil and Gas
- Great Northern Power Development
- Great River Energy
- IOGCC
- Kiewit Mining Group
- Lignite Energy Council
- Manitoba Hydro
- Minnesota Pollution Control Agency
- Minnkota Power Coop.
- Montana Department of Environmental Quality
- Montana Public Service Commission
- Montana-Dakota Utilities Company
- Natural Resources Trust
- North Dakota Department of Health
- North Dakota Geological Survey
- North Dakota Industrial Commission Oil and Gas Division
- North Dakota Petroleum Council
- ☆ North Dakota State Univ.
- Otter Trail Power Company
- Petroleum Tech Research Council
- Petroleum Tech Transfer Council
- Prairie Public Television
- Sask Power
- Saskatchewan Industry and Resources
- Tesoro Refinery
- ☆ U.S. Geological Survey-Northern Prairie Wildlife Research Center
- ☆ Univ. of North Dakota - Energy & Environmental Research Center (EERC)
- University of Regina
- Western Governors Assoc.
- Xcel Energy

Fig. 5. Plains CO_2 Reduction Partnership.

The region includes projects involving two of the four U.S. industrial sources of CO_2 for EOR and five of the 74 CO_2-based EOR projects in the U.S. and accounts for a significant portion of the 7 million tonnes/year of anthropogenic CO_2 currently used for EOR. The Weyburn project, operated by EnCana, involves transporting 4500 tonnes/day of CO_2 by dedicated pipeline from the Dakota Gasification Company in North Dakota to the Weyburn Field in Saskatchewan, Canada.

In considering geologic sequestration, the PCOR Partnership will review information on existing disposal and EOR projects, including the Weyburn CO_2 EOR project in the Williston Basin and the process under way for CO_2 driven ECBM recovery in the Powder River Basin. In addition to the enhanced resource recovery data, deep brine formations and coalfields will be characterized in the PCOR Partnership region.

The PCOR Partnership has developed a web-based Decision Support System (DSS) to house and manipulate regional sink, source, infrastructure data, and model sequestration scenarios. The DSS will allow authorized parties to browse, query, analyze, and download data regarding CO_2 sequestration in the PCOR region. The focus of this system is to compile an interactive data analysis and modeling interface that will provide for the definition and inspection of a wide range of transport and sequestration scenarios.

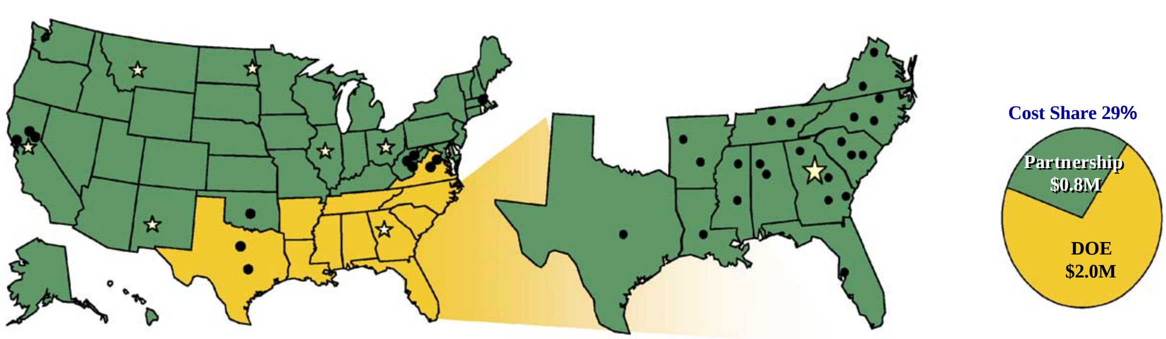
Terrestrial sequestration activities for the PCOR Partnership are focused on two main topics: the characterization and evaluation of the potential for CO_2 sequestration in the marginally productive, semiarid lands in the West-central region of the U.S. and evaluation of the potential for prairie-pothole wetlands to sequester CO_2.

3.5. Southeast Regional Carbon Sequestration Partnership

The Southeast Regional Carbon Sequestration Partnership (SECARB) is being led by the Southern States Energy Board (SSEB). This partnership represents 11 Southeastern states (Alabama, Arkansas, Florida, Georgia, Louisiana, Mississippi, North Carolina, South Carolina, Tennessee, Texas, and Virginia) and includes 35 different partners including academic, research, industrial, and state related organizations (Fig. 6).

The major emitters of CO_2 in the region are power plants, which account for about 75% of anthropogenic carbon emissions, with the next largest source being natural gas processing, which is concentrated in Louisiana. Other CO_2 sources include refineries, cement plants, iron and steel production, and chemicals manufacture. The SRCSP region accounts for about 25% of industrial (including power production) CO_2 emissions in the U.S. or about 890 million tonnes/year.

Potential geologic formations for CO_2 sequestration in the region include deep unmineable coal seams, depleted oil and gas formations, oil and gas bearing shales, active and abandoned gas storage fields, saline formations, and salt caverns/beds. The Black Warrior Basin, which includes portions of Alabama and Mississippi, contains bituminous coal seams varying in thickness from less than 0.3 m to over



Description

The Southeast Regional Carbon Sequestration Partnership, led by the Southern States Energy Board, Norcross, GA, will pinpoint CO2 sources and sinks as well as transport requirements for nine states, and enter these data into a geographical information system database. An outreach plan will be developed so that stakeholders can help identify and implement regional CO2 –sequestration measures. The most promising CO2 methods will be reviewed by permitting and regulatory agencies to determine adequacy of proposed measures, and identify gaps and the need for proposed regulations. Life-cycle storage options will be evaluated according to environmental risk, measurement, monitoring and verification protocols, public acceptance and value-added benefits.

Partners

- ☆ Advanced Resources International
- ● Applied Geo Technologies
- ● Arkansas Oil and Gas Commission
- ● Augusta Systems, Inc.
- ● Center for Energy and Economic Development
- ● Clean Energy Systems, Inc.
- ● Duke Power
- ☆ EPRI
- ● Geological Survey of Alabama
- ● Georgia Environmental Facilities Authority
- ● Georgia Forestry Commission
- ● Georgia Power Company
- ● Interstate Oil and Gas Compact Commission Louisiana
- ● Department of Environmental Quality
- ☆ Massachusetts Institute of Technology
- ● Mississippi State University
- ☆ MSU-Diagnostics Instruments Analysis Laboratory
- ● North American Coal Corporation
- ● North Carolina State Energy Office
- ● Oak Ridge National Laboratory
- ● Phillips Group
- ● Progress Energy
- ● RMS Research
- ● SCANA
- ● South Carolina Dept. of Agriculture
- ● South Carolina Electric & Gas Company
- ● Southern Company
- ● Southern Company Services
- ☆ **Southern States Energy Board**
- ● Susan Rice and Associates, Inc.
- ● Tampa Electric Company
- ● Tennessee Valley Authority
- ● Texas Bureau of Economic Geology University of Texas at Austin
- ● Virginia Polytechnic Institute and State University
- ☆ Winrock International

Fig. 6. Southeast Regional Carbon Sequestration Partnership.

3 m. Tennessee has unconventional gas formations in organic-rich shale with a thickness that in places approaches 100 m. Work is already underway to evaluate the potential for ECBM production from CO_2 injection within the Black Warrior Basin, which has produced 42.5 billion m^3 of coal bed methane (Pashin et al., 2004). Results of this study indicate conservatively that about two decades of CO_2 emissions from power plants serving the basin can be sequestered while potentially increasing coal bed methane reserves by more than 20%. Information from this study is assisting SECARB in characterizing the region.

The region has three basic land types that account for the majority of terrestrial carbon sequestration opportunities: agricultural land, grazing land, and forests, which can be further classified as hardwood or softwood. Forestry and agriculture are important economic sectors in the SECARB region, and changes in land use and management could store significant quantities of carbon. Total terrestrial carbon stored in the region amounts to approximately 14.43 billion tonnes of carbon, which includes 10.7 billion tonnes of carbon as soil organic carbon (Bliss et al., 1995) and 3.73 billion tonnes of carbon as forest biomass (Smith et al., 2001). Significant opportunities exist for terrestrial carbon sequestration in the region. One opportunity is the conversion of marginal agricultural lands, both in the lower Mississippi Valley and the Coastal Plain and Piedmont, back to forests. Other benefits of this conversion would be income from forest products, habitat restoration for wildlife, and flood control.

The region already has a functioning CO_2 infrastructure; CO_2 pipelines exist in Louisiana and Mississippi. This CO_2 is used primarily in the food industry, but significant potential exists for use in EOR and ECBM recovery.

Data collected will be compiled into two GIS databases. MIT will supply the database for capture, transport, and storage, and Winrock will supply the database for terrestrial sequestration. These databases will include information on boundaries of geologic formations, as well as data on economics, regulations, and political/social considerations. Thus, in addition to other information, the GIS will be able to provide estimates of costs associated with the entire lifecycle of a carbon management project.

3.6. Southwest Regional Partnership for Carbon Sequestration

The Southwest Regional Partnership for Carbon Sequestration (SRPCS), led by the New Mexico Institute of Mining and Technology and the Western Governors' Association, includes Arizona, Colorado, New Mexico, Oklahoma, Utah, West Texas, and portions of Kansas and Wyoming (Fig. 7). The partnership includes 50 organizations including academic, industrial, state and federal agencies, an Indian nation, and research organizations.

CO_2 emissions in the region are about 450 million tonnes/year, and 95–99% of these emissions are from fossil fuel combustion (TBEG, 1999). About half of the anthropogenic CO_2 comes from electric power production. Surface

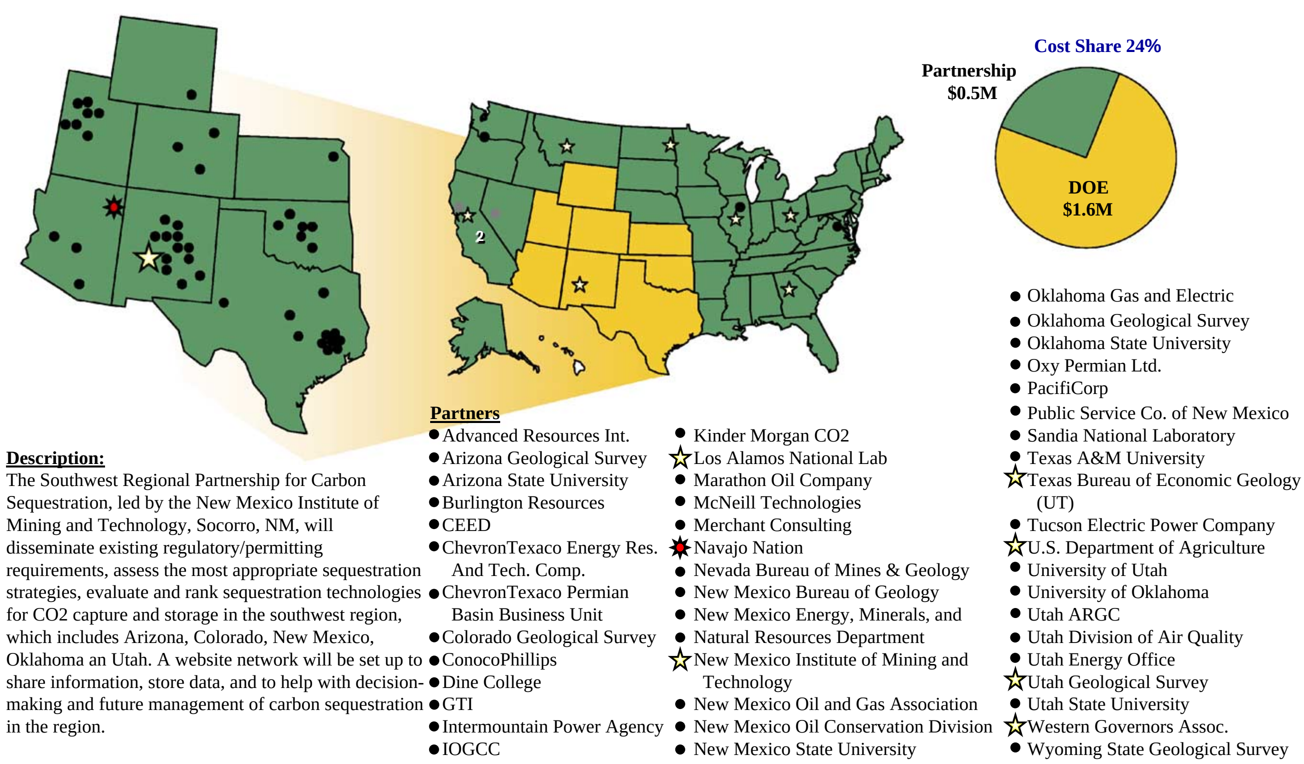


Fig. 7. Southwest Regional Partnership.

mineralization engineering, in which mineral precipitates are produced at the CO_2 source (e.g., at the power plant), is a focus of the partnership.

Geologic storage options in the region include coal beds, natural gas and CO_2 fields, depleted and marginal oil fields, and deep saline formations. The use of CO_2 for EOR has resulted in the annual production of 28 million tonnes of CO_2 from four natural CO_2 fields in the area. The abundance of EOR operations in the region indicates that significant emissions reductions could be achieved by filling new and existing EOR pipelines with anthropogenic CO_2 in lieu of natural CO_2. One option that will be explored is the feasibility of supplanting the CO_2 currently produced from natural CO_2 formations (used for EOR and CBM applications) with anthropogenic power plant CO_2. This may open up the sequestration possibility of "recharging" the natural CO_2 formations with anthropogenic CO_2.

The Southwest region has the potential to store a large amount of CO_2 within the wide range of geologic formations. The region includes over 1000 oil and gas fields with reserves of more than 4.8 billion m^3 of oil and 2.8 trillion cubic m^3 of natural gas, CBM production of over 700 billion cubic m^3 of methane and numerous saline formations whose capacities have not been completely determined. It is estimated that 32–48 billion m^3 of oil equivalent remain in place. For example, the average recovery factor for Oklahoma is about 20%. With a ready supply of CO_2, even a 1% increase in recovery would mean production of tens of millions of cubic meters of oil.

CO_2 mineralization is a novel concept for binding CO_2 in a solid form, which eliminates the need for long-term monitoring and any concern over the long-term fate of the CO_2. CO_2 mineralization is an ongoing natural process, but an engineered process that could be implemented at a rate and scale that is meaningful with respect to sequestration remains an active research challenge. One approach for the assessment of the CO_2 mineralization option in the Southwest focuses on characterizing the location and volume of potential subsurface mineralization storage sites provided by ultramafic rocks and brines.

Although terrestrial CO_2 sequestration appears to be a viable alternative in several parts of the region, the rate of CO_2 emissions caused by drought-related forest fires and wind dispersal of cropland soil may increase under a range of plausible, dryer-than-usual climate futures. In some parts of the region, it will be important to evaluate the tradeoffs associated with using saline formations for CO_2 sequestration, when the water might ultimately be needed, after desalination, as a source for human consumption.

Forests have the potential to sequester 500–1500 kg/ha/year of carbon, depending on climate, soil, and management practices. In the more humid prairies of the Eastern portion of the region, sequestration rates can approach 500 kg/ha/year. At the arid extreme, rangeland carbon sequestration may be less than 10 kg/ha/year (NRCS, 2000).

The Southwest region contains the principal CO_2 pipeline infrastructure in the country. Kinder Morgan will assist the partnership by providing its database and helping with transportation assessments.

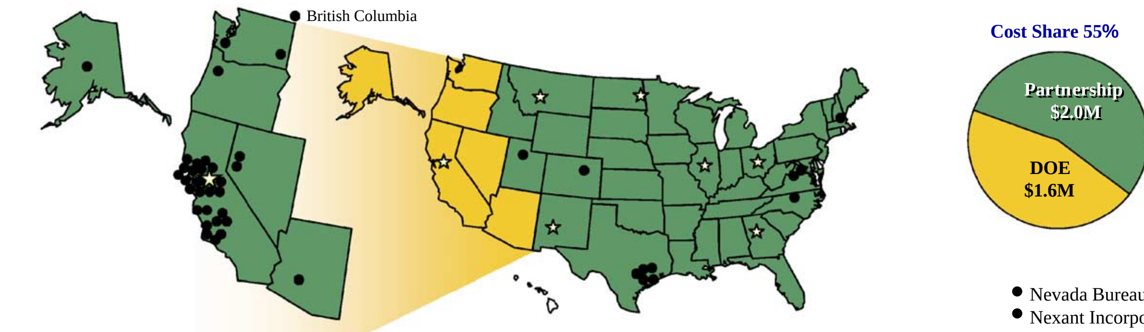
A quantitative ranking of the most promising opportunities for capture, storage, and transport of CO_2 in the region will be achieved using a system dynamics decision framework based on performing model simulations involving both discrete sequestration options and systems options. Model results, which will form the basis for the rankings, will include such metrics as total lifecycle costs, total carbon sequestered, reduction in carbon emissions, and potential side benefits. Potential risks will be assessed for each sequestration option, and appropriate MMV approaches will be assessed and recommended. The partnership is completing an Integrated Assessment Model (IAM) which will be used to model "what if" scenarios for different sequestration technologies and storage sites, regional economic and energy conditions, and the effect of different time frames for sequestration.

3.7. West Coast Regional Carbon Sequestration Partnership

The West Coast Regional Carbon Sequestration Partnership (WESTCARB), led by the California Energy Commission, includes Arizona, California, Nevada, Oregon, Washington, North Slope of Alaska, and the Canadian Province of British Columbia (Fig. 8). The partnership consists of 52 organizations, including academic institutions, energy companies, national laboratories, private companies, and governmental agencies.

In 1999 the region generated about 11% of the nation's anthropogenic CO_2 emissions. Within the region, transportation accounted for 53% of the emissions, while the industrial sector accounted for 23% and the utility sector 13%. CO_2 emissions from the industrial and utility sectors (point sources most amenable to capture) amounted to 62 million tonnes of carbon equivalent per year, not including 4 million tonnes for the North Slope of Alaska (Benson, 2000). In addition to power plants, the major industrial sources are cement and lime plants, petroleum refineries, and gas processing facilities. The region offers outstanding options for both geologic (including value added uses such as EOR) and terrestrial sequestration. Furthermore, California and Oregon have a legal framework in place for treating CO_2 emissions offsets from forestry-based projects. There is also technical expertise in the region for using CO_2 for EOR operations. The region has other geologic features that offer options for CO_2 sequestration, such as brine formations.

The Pacific Coast Province is of prime interest because of its thick sediment sequence and oil and gas fields, which are found primarily in California's Central Valley. It is estimated that the CO_2 demand for EOR operations could reach 10–20 million tonnes/year. There could also be a significant demand for CO_2 for EOR in Alaska. The



Description:
The West Coast Regional Carbon Sequestration Partnership, led by the California Energy Commission, Sacramento, Ca., plans to identify, characterize and locate CO2 emission sources in the region and determine long-term capturing and sequestering methods by enlisting the help of numerous federal, state, local government agencies and industry sources. Technology discussions, regional meetings and joint research will maintain an open dialogue with stakeholders so that a regional strategy for terrestrial and geologic carbon-sequestration projects that meet the areas' needs for the near- and long-term can be developed. Demonstration projects will be identified and plans for their effective implementation will be held.

Partners
- Advanced Resources Int.
- Aera
- American Petroleum Institute
- Automated Geographic Reference Center
- B.C. Ministry of Energy and Mines
- BKI
- British Petroleum
- California Climate Registry
- California Dept. of Forestry and Fire Protection
- California Dept. of Oil, Gas and Geothermal Resources
- ☆ California Energy Comm.
- California Geologic Survey
- California Polytechnic Inst
- California State University at Bakersfield
- Cement Industry Environmental
- Consortium
- ChevronTexaco
- Clean Energy Systems
- Conoco Phillips
- CSU, School of Natural Sciences & Mathematics
- Dept. Env. City & County of San Francisco
- Electricity Innovation Inst.
- EPA California
- Golder Associates
- Greenwood Enterprises
- Kinder Morgan
- ☆ Lawrence Berkeley National Laboratory
- Lawrence Livermore National Laboratory
- M. Theo Kearney Foundation of Soil Sci.
- Massachusetts Inst. Of Technology
- National Council for Air and Stream Improvement
- Nevada Bureau of Mine and Geology
- Nexant Incorporated
- Occidental Petroleum
- Oregon Dept. of Forestry
- Pacific Forest Trust
- PacifiCorp
- Region 9 EPA
- Salt River Project
- San Francisco Department of the Environment
- Science Strategies
- SFA Pacific
- Shell
- Sierra Pacific Resources
- Stanford Global Climate Energy Project
- Terralog Technologies
- TransAlta
- University of Alaska Fairbanks
- Washington State Dept. of Natural Resources
- Western Interstate Energy Board
- Western States Petroleum Association
- ☆ Winrock International

Fig. 8. West Coast Regional Carbon Sequestration Partnership.

capacity of the Pacific Coast Province oil fields is dwarfed by that of brine formations in the Central Valley. The Basin and Range Province encompasses all of Nevada and much of Arizona, California, and Oregon. The potential CO_2 storage capacity of the basins has not been studied, but thick sedimentary sections may contain brine formations with adequate seals to contain injected CO_2. The Columbia Plateau of Washington and Oregon is covered by hundreds to thousands of meters of basalt underlain by volcanic ash and, deeper, by sediments. The practicality of accessing these sediments for sequestration has not been determined. The sediments of the Colorado Plateau offer significant potential sequestration capacity.

The West Coast region has a wealth of forest and agricultural lands where improved management practices could sequester substantial quantities of carbon. For forests, the focus will be on three major types: the Pacific Coast forests of Northern California, Oregon, and Washington; the Inland Empire forests of Eastern Washington and Oregon and the North and Central portions of California's Sierra Nevada range; and the ponderosa pine and piñon-juniper woodlands of California's Southern Sierra Nevada, as well as Nevada and Arizona. To develop the sequestration capacity baseline, the partnership will apply an existing analytic framework developed by Winrock (EPRI and CEC, 2004). This framework incorporates measurement and monitoring procedures and a risk/benefit model used to evaluate more than one million ha around the world.

WESTCARB will integrate the data it assembles into a comprehensive GIS database to support analyses of regional carbon management strategies and potential pilot sites. They will address environmental efficacy issues, compile regulatory and permitting data, and establish a strategy applicable to pilot and larger-scale projects. In addition, educational materials on key carbon management issues will be developed, a multi-stakeholder technology and policy conference will be conducted, and an action plan for public outreach and education will be developed. The WESTCARB GIS, with data on sources, suitable geologic formations, and risk factors, such as faults and population centers, is being used to screen for candidate storage sites in the region. As an example, WESTCARB has eliminated 74 of the 101 basins in California based on the established site screening criteria. Finally, WESTCARB will craft a portfolio of capture, transport, and geologic storage and terrestrial sequestration solutions appropriate for short-, medium-, and long-term carbon management goals in the West Coast region.

4. Conclusions

It is likely that CO_2 sequestration in some form will be required to meet the goal of long-term reduction of CO_2

emissions. However, because of the wide diversity of geology, terrain, and climate across the U.S., the best sequestration strategy will differ among different geographic regions of the country. To ensure that each region adopts optimal technology, the DOE has selected a network of seven regional partnerships to examine CO_2 sequestration issues in their regions of the country. Each partnership is examining CO_2 sources; geologic formations with potential for CO_2 injection; indirect terrestrial sinks; the existing and necessary CO_2 transportation infrastructure; MMV tools and protocols, regulatory issues related to project implementation; and the public outreach and education needed to gain stakeholder and public support. A major goal of this effort is to combine the efforts of all the partnerships into the national carbon sequestration database.

In the course of Phase I, the Partnerships have achieved the objectives of the program by (1) establishing a national network of companies and professionals working to support sequestration deployments, (2) creating a carbon sequestration atlas for the U.S., (3) obtaining an improved understanding of the permitting requirements that future sequestration deployments will need to meet, (4) raising awareness and support, both within industry and the general public, for carbon sequestration as a GHG mitigation option, (5) identifying and vetting priority opportunities for sequestration field tests, and (6) establishing a series of protocols for project implementation, accounting, and contracts.

Additional federal funding will be provided in Phase II, expected to be operative in 2006. In Phase II, while focusing on field validation tests at regional locations with the greatest promise of storing large quantities of CO_2, the selected partnerships will also prove the environmental efficacy of sequestration, verify regional CO_2 sequestration capacities, satisfy project permitting requirements, and conduct public outreach and education activities. The partnerships provide a critical link to the U.S. plans for FutureGen, a highly efficient and technologically sophisticated coal-fired power plant that will produce both hydrogen and electricity with near-zero emissions.

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